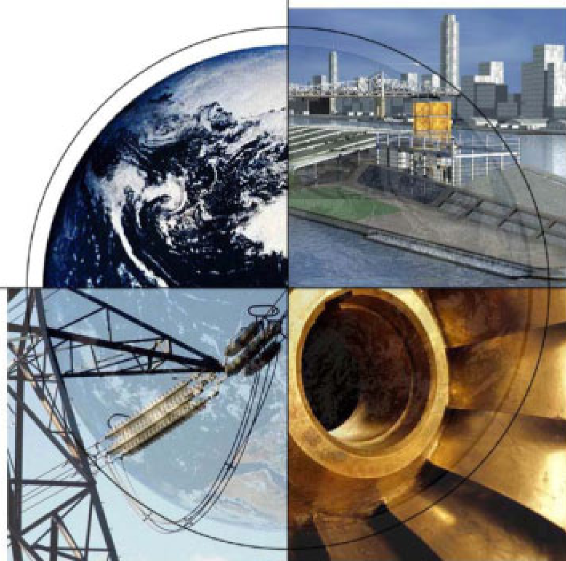
US DOE's FE Turbine Program



Enabling Turbines for Coal-Based Power Systems

2005 ASME IGTI Turbo Expo
Reno, Nevada, USA
June 6-9, 2005

Richard A. Dennis; Technology Manager
National Energy Technology Laboratory

Presentation Outline

- Goals and Objectives
- Program Approach
  - Selected projects
- New Initiatives in FY 05
- Summary

Goals
Central Systems- Advanced Power

- By 2010, complete R&D for advanced gasification combined cycle technology that can produce electricity from coal at 45-50% efficiency (HHV), less than 3 ppm NOx emissions and at a capital cost of $1,000/kW or less.
- By 2012, complete R&D to integrate this technology with CO_2 separation, capture, and sequestration into a near zero-emission configuration(s) that can provide electricity with less than a 10 % increase in cost of electricity.
- By 2020, develop near zero emission plants (including carbon) that are fuel-flexible and capable of multi-product output and efficiencies over 60% with coal.

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Approach to Goals

Turbine Program Contribution to Goals

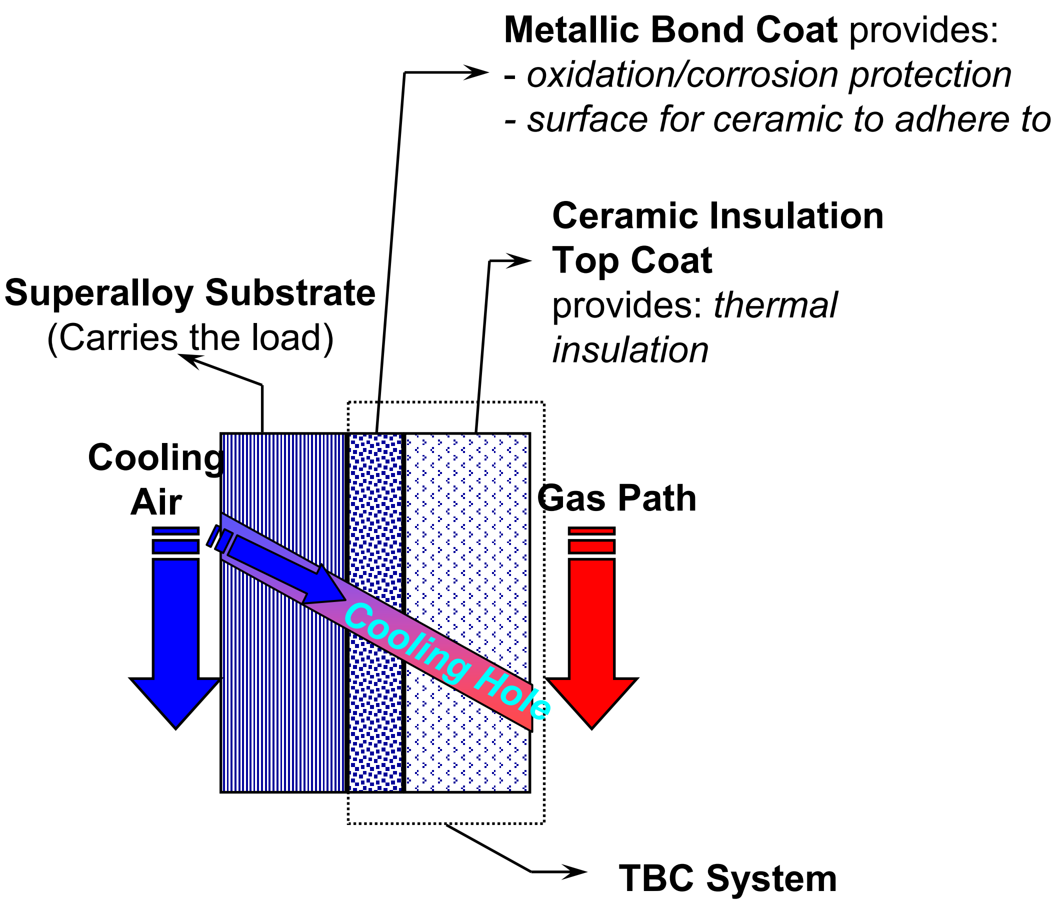
- **Increase combined cycle (CC) efficiency by 2 – 3 % points above current CC systems fueled with syngas**
  - Increase firing temperature
  - Improve TBC and redirect cooling air
  - Improved cooling techniques
  - Optimize cycle / plant configuration
  - Combustors with lower pressure drops
- **Reduce NOx emissions to less than 3 ppm without SCR**
  - Develop advanced combustion technologies
    - Catalytic combustion
    - Premix technology
- **Reduce capital cost of the CC system by increasing specific power output**

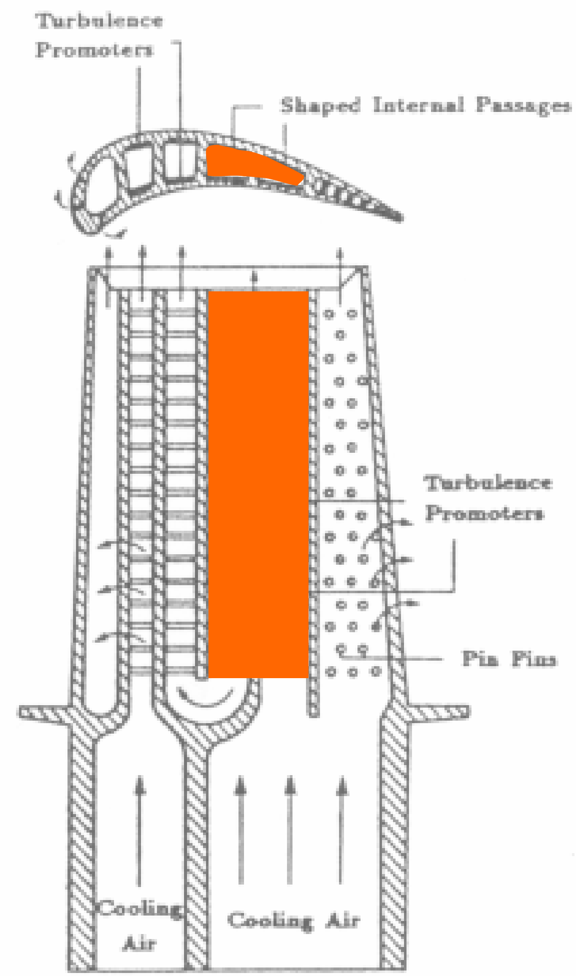
Effect of 7FA vs. 7FB Firing Temp

(NETL ASPEN Simulation of Wabash Design)

	ASPEN 7FA	ASPEN 7FB
Fuel	Syngas	Syngas
Steam Injection (lbs/sec)	69.9	69.9
GT TIT (ºF)	2279	2363
Exhaust Temp (ºF)	1128	1166
GT / ST Power (MW)	211.6 / 115.2	230 / 123.8
% Eff. (HHV)	39.39	40.43

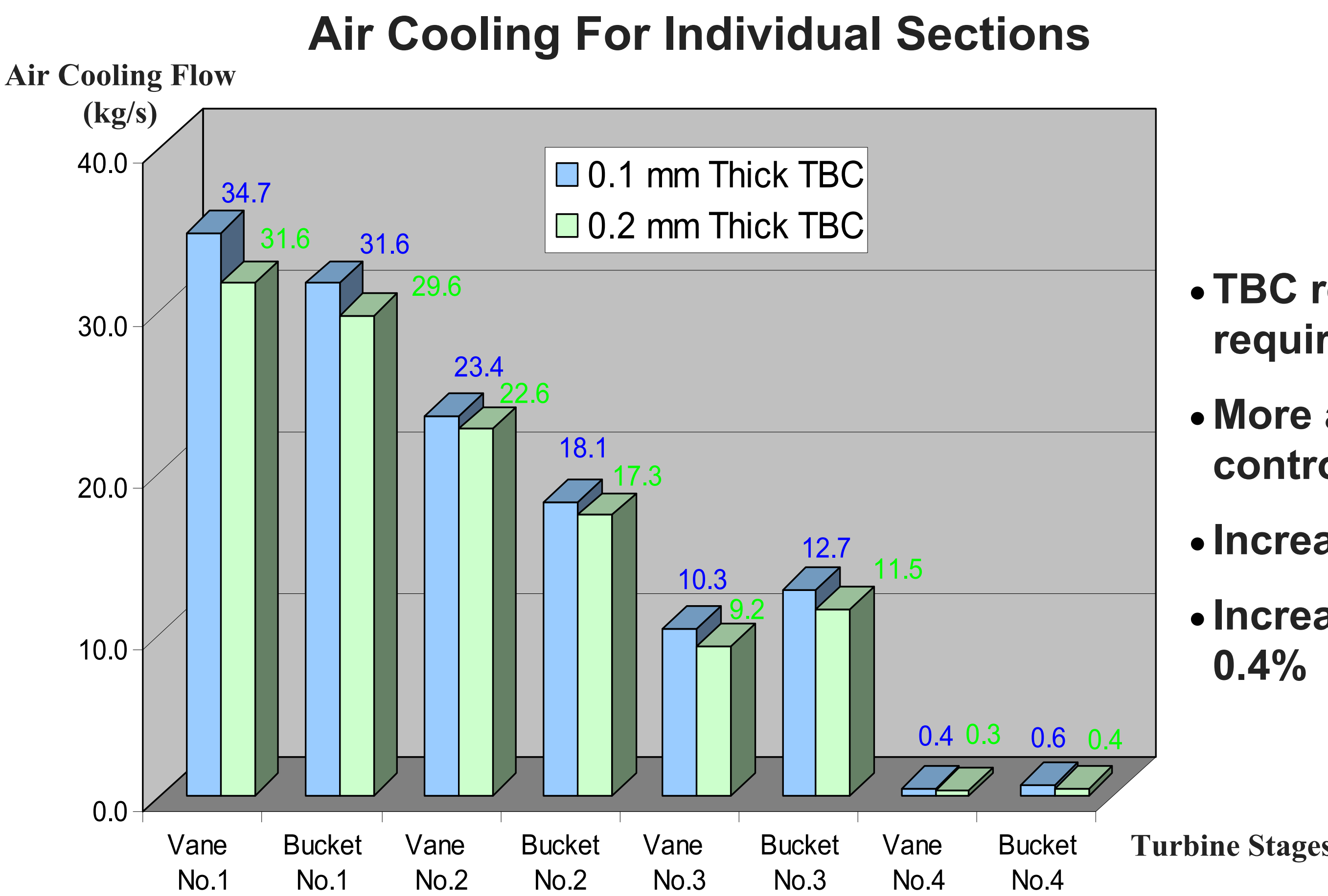
TBCs and Internal Cooling Manage Blade Strength





(J.C. Han 1988)

Improved TBC Has Synergistic Benefits



- **TBC reduces cooling flow requirements by 7%**
- **More air available for NOx control**
- **Increase expansion work out**
- **Increase CC efficiency by 0.4%**

Note: For a 4 stage machine, F machines have 3 stages

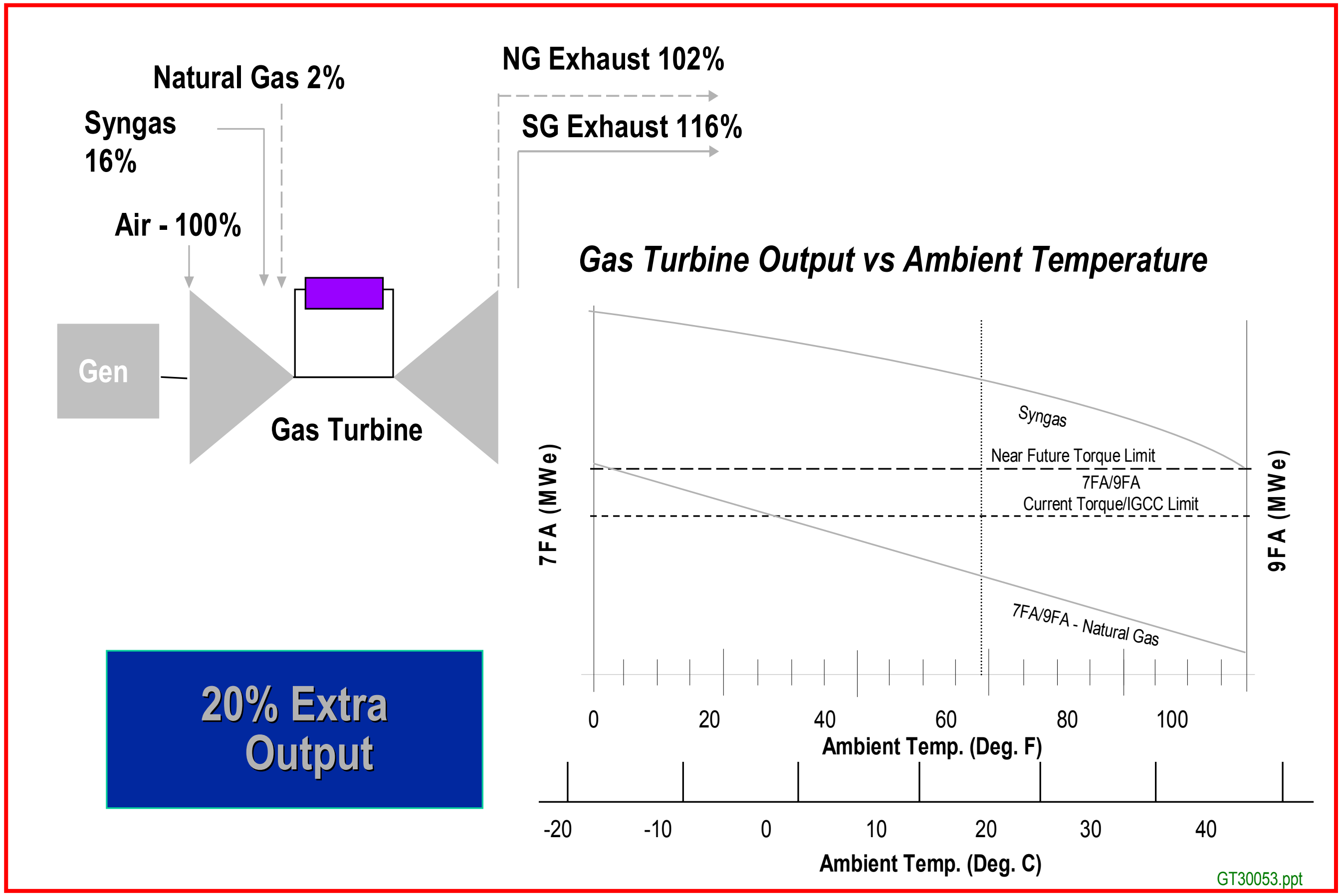
Ref: Fig.5.2 of VDI-Report 448, 2001

Performance Target
Reduce Emissions

- **Goal:** *Reduction in NOx emissions for syngas to < 3 ppm*
- **State of the art**
  - Dry Low NOX (DLN) for GE 7EA, FA and 6B gas turbines on natural gas 9 ppm at 15% O_2
  - H-Class w/ DLN demonstrated 25 ppm, potential for 9 ppm
  - After market retrofits have demonstrtated 3 – 5 ppm NOx in smaller machines
  - Tampa is regulated to 15 ppm NOx and routinely operates around 10 -11 ppm (diffusion flame combustion)
  - Wabash is regulated at 25 ppm NOx and has operated around 18 ppm.
- **Approach to goal**

  Extend the lean pre mix limit (TVC, H_2, others?), enhanced diffusion flame combustion or catalytic combustion.

IGCC Turbine Output Enhancement



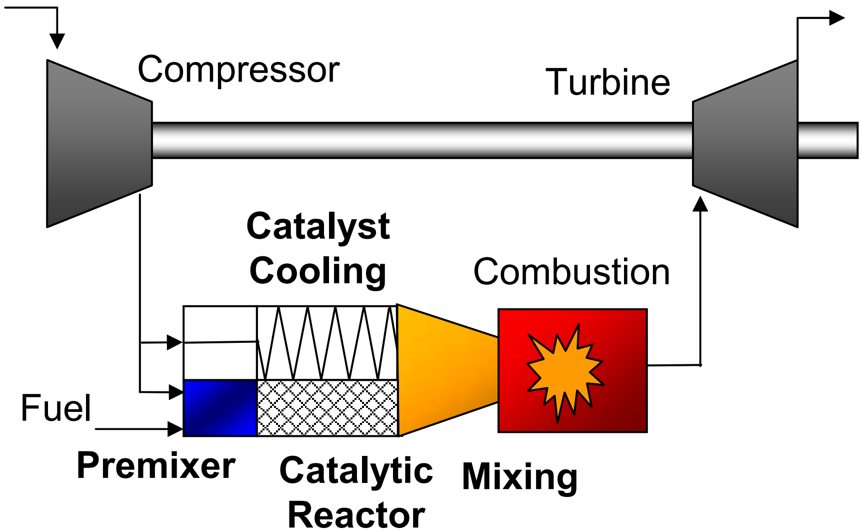
Model	NG-SC	Syngas-SC	Net-IGCC
6FA	70	90	126
7FA	172	197	280

Ref: GE

Selected Projects Addressing These Goals

Ultra-Low NOx Catalytic Combustion for IGCC Plants

Precision Combustion, Inc. (41721)



Objectives

Develop an ultra-low NOx combustion system for IGCC power plants burning coal-derived (syngas) fuel.

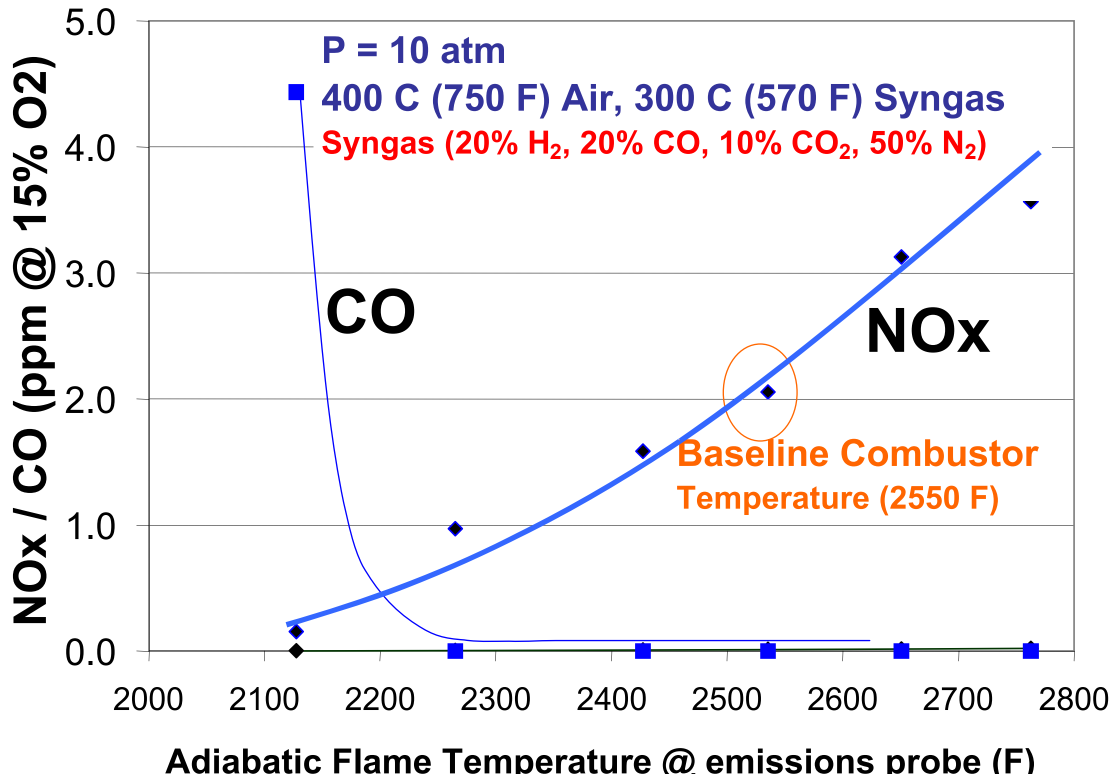
Duration: 3/21/03 – 9/30/05

Benefits

- **Near-zero NOx emissions without post-combustion controls or efficiency penalty**
- **Catalytically stabilized combustion extends lower Btu limit for syngas operation**

Ultra-Low NOx Catalytic Combustion for IGCC Plants

Precision Combustion, Inc. (41721)

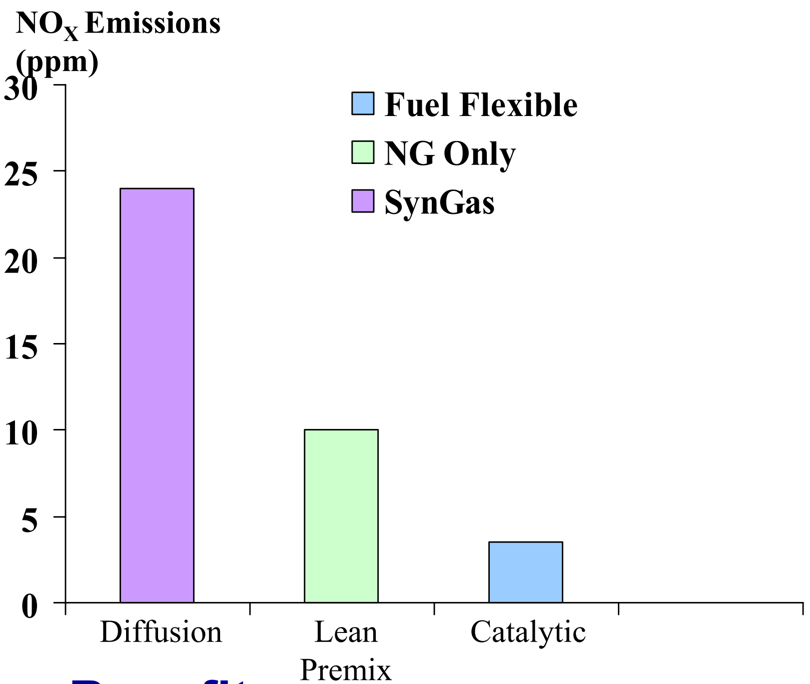


Results

- Confirmed <3 ppm NOx and good CO emissions at 10 atm
- Good OEM support
- ASME 2004 best paper award
- Results on pure hydrogen are promising

Catalytic Combustor for Fuel-Flexible Turbine

Siemens Westinghouse Power Corporation (41891)



Objectives

Develop / demonstrate a cost effective, fuel flexible catalytic combustor that will achieve ultra low NOx emissions (2 ppm)

Duration: **9/30/03 – 6/30/07**

Benefits

- **Fuel Flexible (Syngas, H2, NG)**
- **Low NOx with stability**
- **Avoids Post-Combustion Clean-Up**
- **Retrofit Applicable**

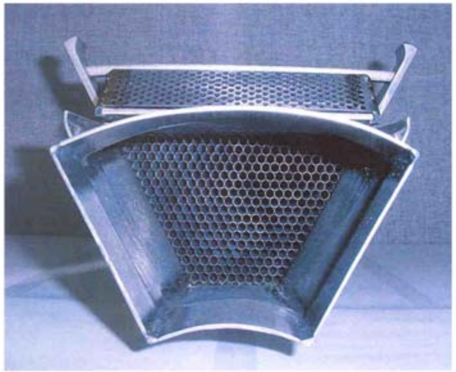
Catalytic Combustor for Fuel-Flexible Turbine

Siemens Westinghouse Power Corporation (41891)

Results

- **Benchmarked technology options**
- **Established feasibility of catalytic syngas combustion**
- **Demonstrated light off of SWPC coating on NG and syngas**
- **501F configuration tested in full pressure test rig**

Siemens Westinghouse Catalytic Module

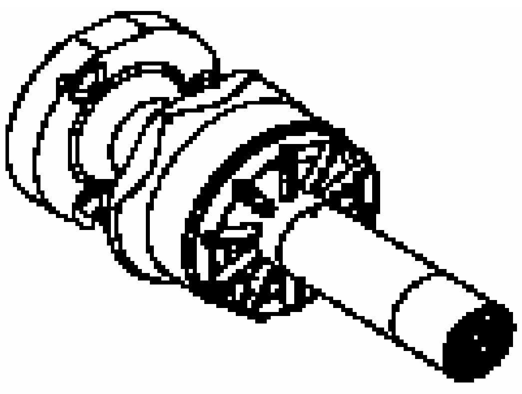


Catalytic Basket W501D5 Retrofit

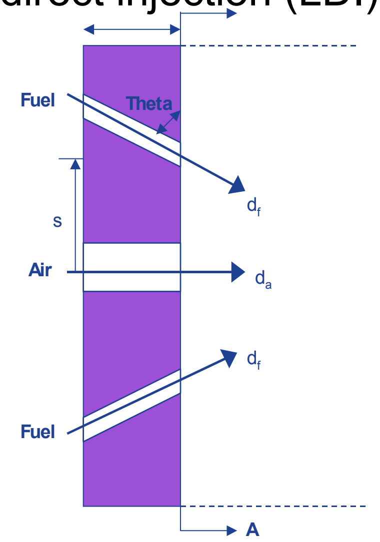
Premixer Design for High Hydrogen Fuels

GE Energy *(*DE-FC26-03NT-41893*)*

DACRS swirl based premixer



Lean direct injection (LDI)



Objectives

- Design lean premixer for high H_2 IGCC fuels
- Demonstrate single digit NOx emission at advanced GT cycle conditions
- Minimize diluent requirement for:
  - NOx abatement
  - Flame holding / auto-ignition resistance

Duration: **18 months**

Benefits

- Designs to burn High H2 fuels with lower NOx and less diluent.
- Validated CFD models for use in H2 combustion.
- Path for further improved IGCC/High H2 combustor development.

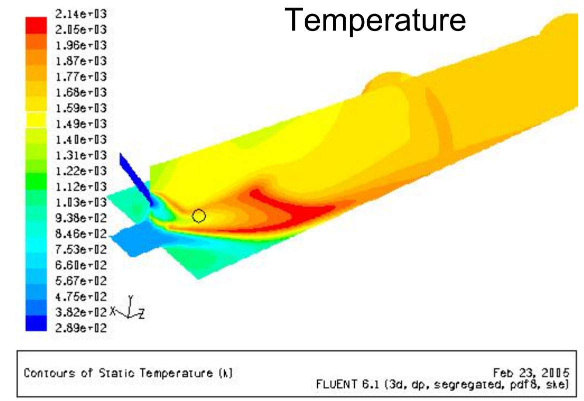
Premixer Design for High Hydrogen Fuels

GE Energy *(*DE-FC26-03NT-41893*)*

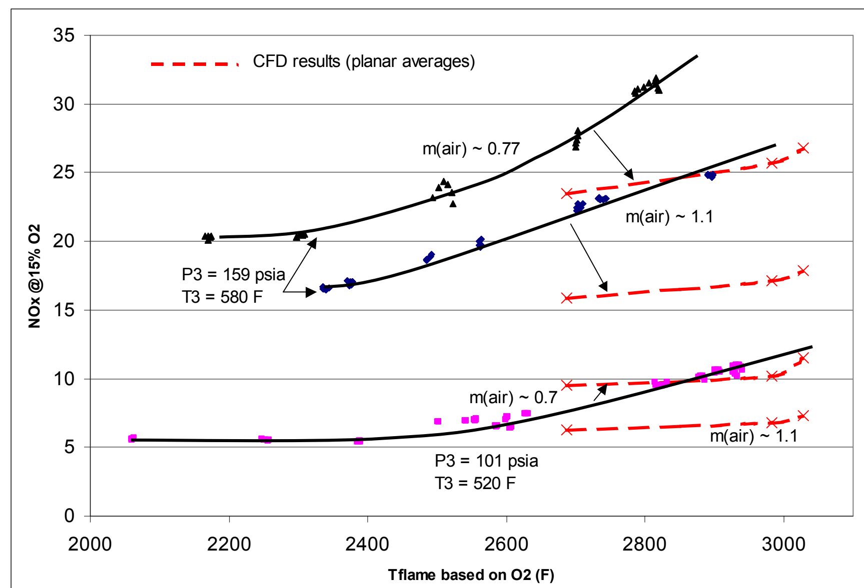
Results to Date:

- High flame holding data
- Lean direct injection results showing path to low NOx
- CFD validated against LDI results
- Swirler based premixer cold flow model being validated against test results
- Models of high H2/air mixing performance for different mixer concepts.

LDI CFD
of combustion



LDI CFD
compared to
experimental
results.



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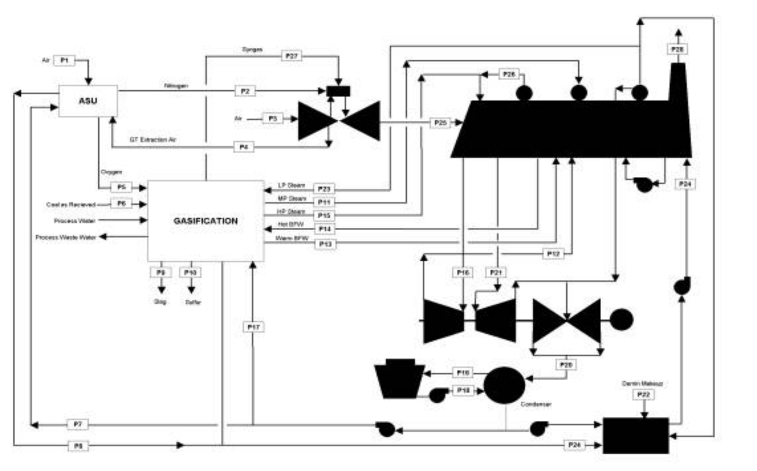
System Study for Improved Gas Turbine Performance for Coal/IGCC Applications

GE Energy (DE-FC26-03NT-41889)

Gas Turbine Plant IGCC Simulation Model



Benefits

- Gas Turbine Design Concepts that meet future DOE coal IGCC power plant goals
- Validated Gas Turbine models for FutureGen/ Hydrogen Turbine program
- Path for fuel flexible Gas Turbine development including carbon free fuels

Objectives

- Identify/Prioritize Gas Turbine Requirements for Coal/IGCC Power Plants
- Identify/Prioritize Gas Turbine Cycle Design Parameters
- Determine Performance Influence of Gas Turbine Cycle on Key IGCC plant parameters
- Perform Tradeoff Analysis of Various Gas Turbine Cycle Design Options
- Recommend suitable Gas Turbine Cycle Design concepts
- Assess performance impact of carbon capture

Duration: **21 months**

System Study for Improved Gas Turbine Performance for Coal/IGCC Applications

GE Energy (DE-FC26-03NT-41889)

Results to Date

- **4 Key IGCC Parameters**: IGCC Net HHV Efficiency, IGCC Specific Output, GT Specific Output, NOx Emissions
- **7 Important GT Power Island Parameters**: Availability, Product Cost, Efficiency, Air Integration flexibility, syngas & diluent supply conditions and syngas NO_x Capability

Gas Turbine Cycle Influence Coefficients on IGCC Performance

Turbine Cycle Parameter	IGCC Net Eff	IGCC Net kW	GT Output	NOx
Firing Temperature	0.584	3.113	2.948	2.604
Turbine Isen Efficiency %	0.784	0.784	2.070	0.000
Compressor Isen Efficiency %	0.252	0.669	0.937	0.130
Compressor Air Flow	-0.026	0.970	1.007	0.000
Compressor Pressure Ratio	-0.048	-0.361	-0.144	0.910
Turbine Cooling Flow	-0.045	-0.180	-0.208	0.525
Combustor DP/P	-0.010	-0.009	-0.026	0.207
Nitrogen Dilluent Flow	0.020	0.192	0.294	-3.869
Diluent Supply Temperature	0.063	-0.055	-0.058	0.715
Syngas Supply Temperature	0.030	-0.110	-0.078	0.840
Air Extraction	-0.003	-0.087	-0.154	0.044

- **11 vital GT Cycle Parameters:** Firing Temperature, Combustor Options, Turbine and compressor Efficiency, Compressor Pressure Ratio, Cooling Flows, amount of Air Extraction, Syngas Supply Temperature, Diluent Supply Temperature, Compressor Air Flow and Diluent Flow
- **18 GT cycle Design Options**
- **3 Recommended GT Design Concepts**

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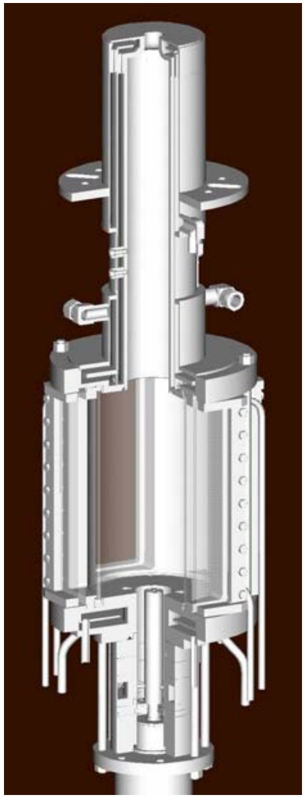
NETL In-house Combustion Sciences

Energy System Dynamics Focus Area



Sim-Val High Pressure / Temperature Test Facility

Objectives

- Assess effects of H_2 on lean extinction limit and combustion stability
- Evaluate advanced combustor designs for 3 ppm NOx goal
- Generate LES validation data for CFD models
- Improving scientific understanding of flame dynamics at low-emission conditions

Benefits

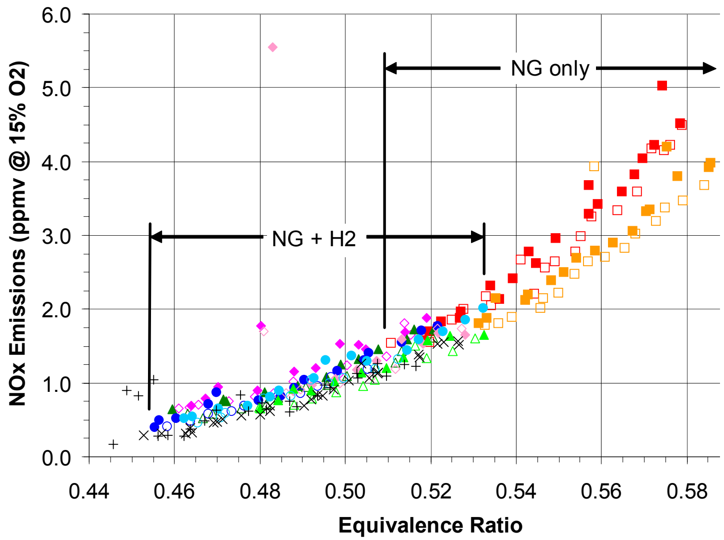
- Provides fundamental combustor design and control data for high hydrogen fuels (coal syngas and H_2)
- Provides fundamental effects of H_2 fuels

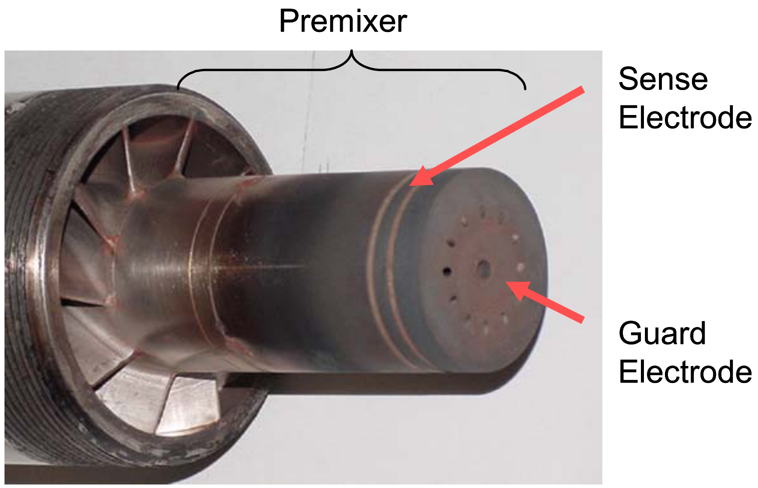
NETL In-house Combustion Sciences

Energy System Dynamics Focus Area

Results

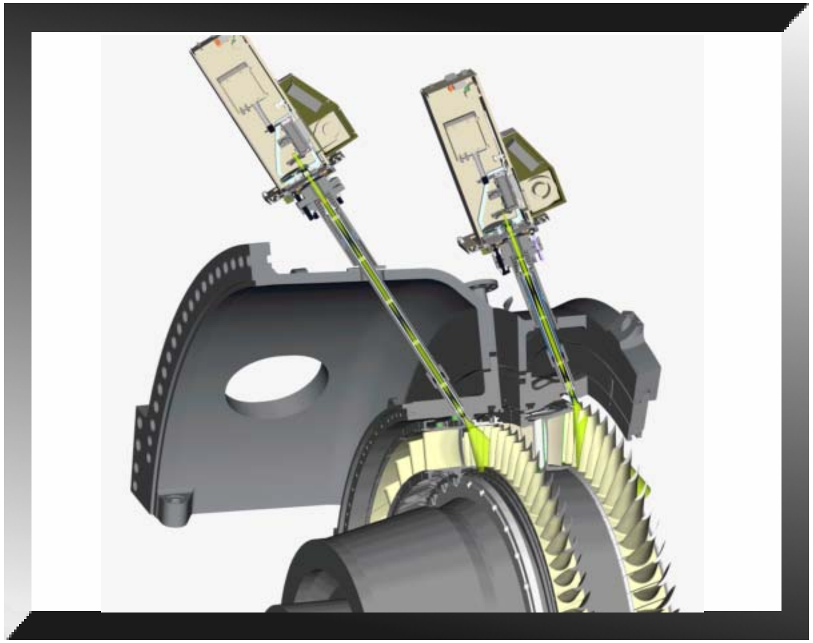
- Addition of small amounts (5 – 10%) of H_2 to NG fuel significantly decreases lean extinction limit (reducing NOx emissions) and extends stability envelope
- Advanced Trapped Vortex Combustor tests showed NOx emissions < 3 ppm, combustion efficiency > 99%, low pressure drop and dynamic stability
- Experimental and analytic model developed to test impedance control concept on commercial turbine fuel injector. (OEM field tests April, 2005)
- With CRADA partner, successfully applied CCADS to multi-nozzle turbine combustors, demonstrating flashback detection and sensitivity to combustion dynamics. (OEM field tests Jul. & Nov. 2004)





On-Line TBC Monitoring for Real-Time Failure Protection

Siemens Westinghouse Power Corporation, (41232)



Objectives

Design build and install a gas turbine blade and vane thermal barrier coating (TBC) monitor for real time detection / formation and progression of critical TBC defects. The monitor will track and report on the progression of TBC defects, estimate remaining TBC life, and notify operations of impending damage.

Duration: 4 Year Program

Benefits

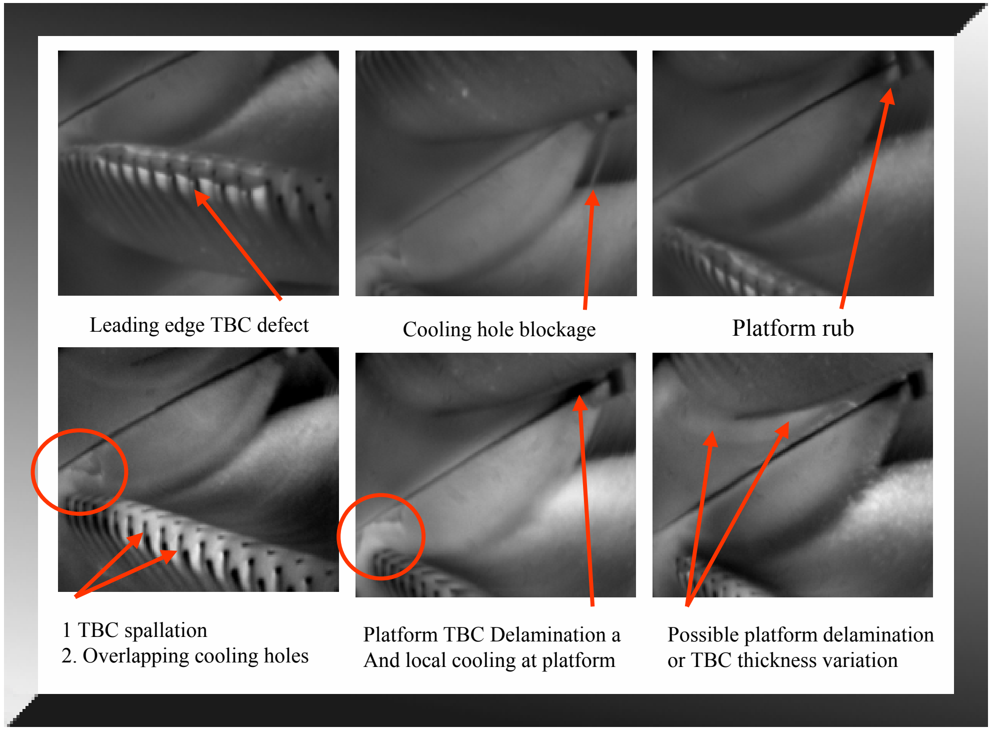
- Higher equipment availability
- OEM design tool
- Reduced Maintenance Costs

On-Line TBC Monitoring for Real-Time Failure Protection

Siemens Westinghouse Power Corporation, (41232)

Results

- Proof-of-concept tests (2001) profiled key interactions between infrared instrumentation, and absorption characteristic
- Characterize emissions from TBC defects (APS)-Infrared emission from TBC and associated progressions of deterioration was characterized, (debond growth, spall). The deteriorating TBC emission demonstrates a local step change in emissivity.
- Installation (2003) of the prototype dual spectral response On-line TBC Monitor
- Developed TBC Remaining Life Prediction Model / completed prototype testing (5/03)
- Installation (10/04) of full scale system at Empire State-Line Unit (501FD2) monitored in real-time, the condition and performance of row 1 and row 2 turbines blades



New Program Elements

"Enabling Turbine Technologies for High-Hydrogen Fuels"

Solicitation Topic Areas

- **Hydrogen Turbines for FutureGen**
- **Oxy-Fuel Rankine Cycles**
  - Turbine Development
  - Combustor Development
- **Advanced Brayton Cycle Turbines**
- **Mega-Watt Scale Turbines for Hydrogen Utilization**
  - Highly Efficient Zero Emission Hydrogen Combustion
  - H_2 Fuel Augmentation to Reduce NO_x
  - H_2 Co-Production in Industrial Applications
- **Novel Concepts for the Compression of Large Volumes of Carbon Dioxide**

The full solicitation can be found at:
https://e-center.doe.gov/iips/faopor.nsf/

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Summary / Conclusions

- FE Turbine program completely focused on coal-based fuels (Syngas and Hydrogen)
- Several combustion technologies have demonstrated ability to attain the 3 ppm NOx goal
- Cycle optimization and increasing firing temp. show promise for attaining efficiency goal
- Adding value to turbines for IGCC applications will reduce plant cost and COE
- FY 05 Turbine Program solicitation will provide turbine technology for FutureGen and other near zero emission technologies / systems